Fire and Climate Interactions in the Sierra San Pedro Martir Baja California, Mexico

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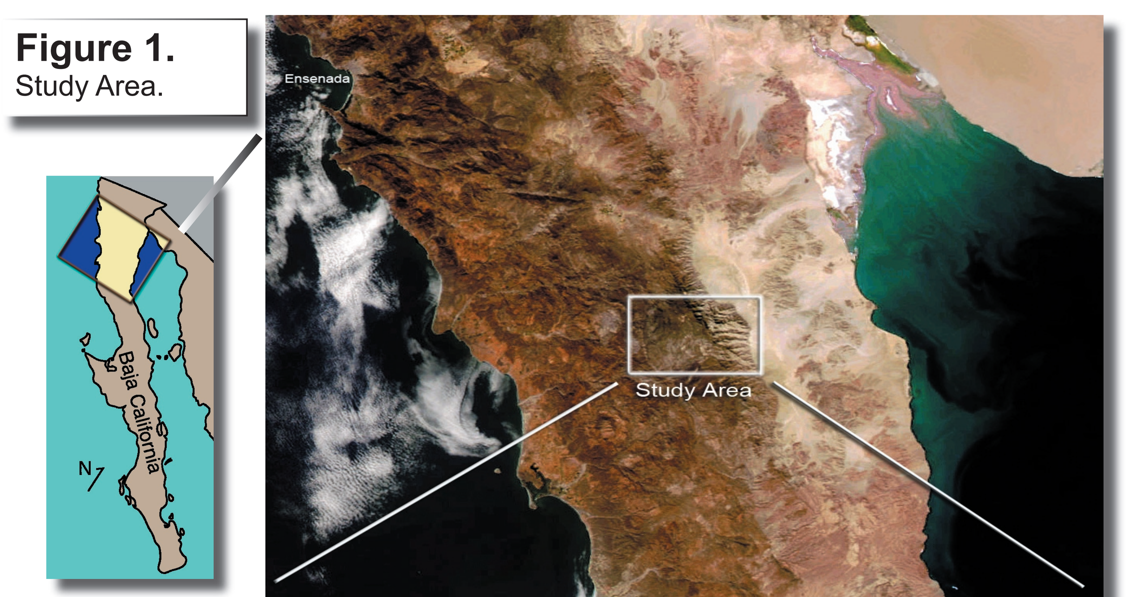
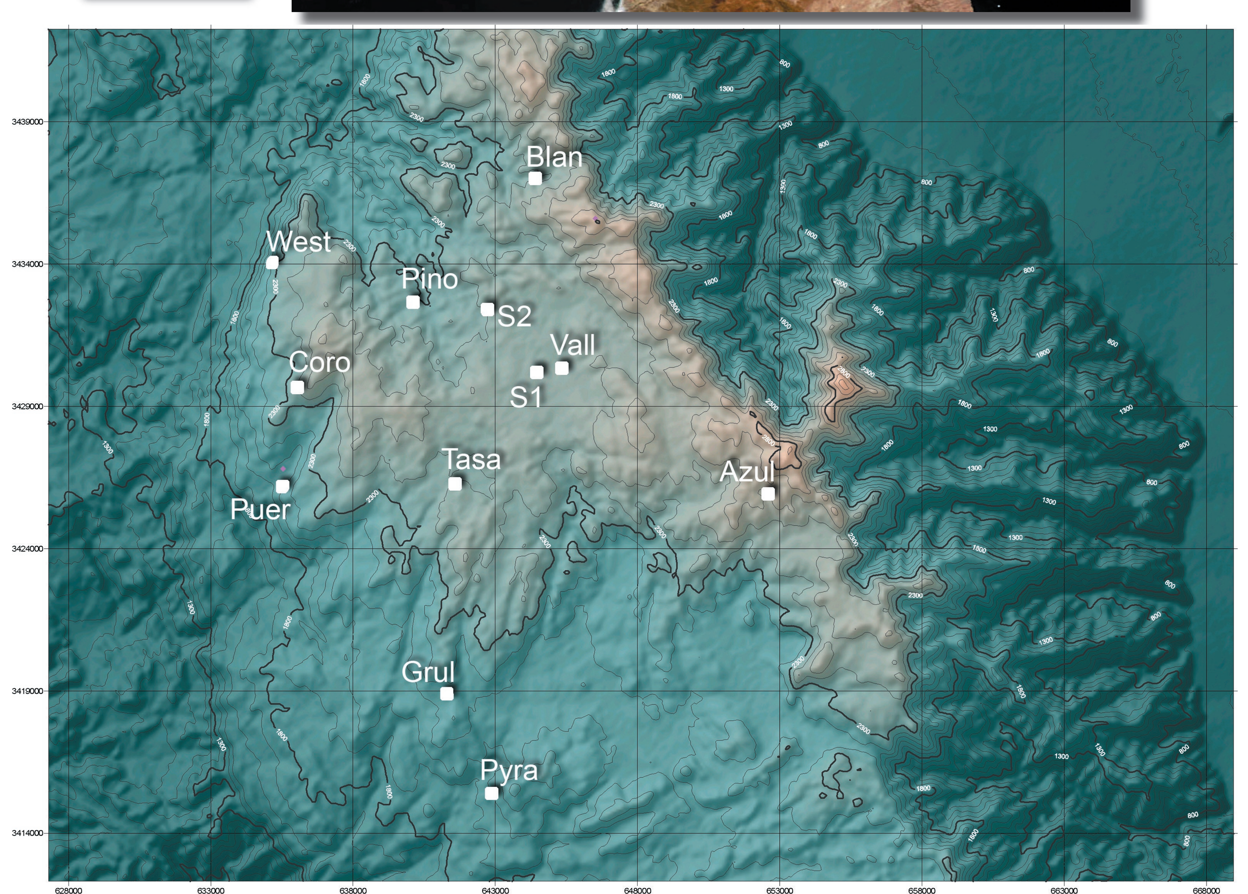
ABSTRACT

Fire regime characteristics were developed from 257 crossdated, fire-scarred specimens collected on 12 sites dispersed in the conifer forests of the Sierra San Pedro Martir (SSPM). The fire-scar record indicates that fire occurrence and extent have varied considerably during the period of analysis (A.D. 1700 – 1990). Periods of low fire occurrence are recorded for the early 1800s and the late 1900s. Conversely, the 1700s and early 1900s were periods of relatively high fire occurrence. Seasonality of fires, determined from intra-ring position of fire scars, varied with location of the sites in the SSPM and changed over time. Fires were predominantly earlier on more exposed and lower elevation sites and were generally later in cold-air drainage and higher elevation sites. Additionally, fires in the 1700s were generally earlier than fires in later years. We compared fire occurrence and extent with tree-ring derived indices of the Palmer Drought Severity Index (PDSI), Pacific Decadal Oscillation (PDO), and a Southern Oscillation index (NINO3). For the entire period of analysis, comparisons of the fire record with PDSI and NINO3 indicate that widespread fires were associated with dry years while years of no fires were wet. Additionally, widespread fires were associated with shifting phase of the PDO – most commonly when the PDO is transitioning from a warm to a cool phase. Fire regime characteristics, and presumably their influence of ecosystem patterns, vary geographically and temporally in association with variation in climatic factors.

Figure 1.
Study Area.





Location of Sample Sites

INTRODUCTION

Fire regimes have been shown to vary over time and space at many scales (Heyerdahl et al. 2002, Taylor and Skinner 1998, 2003, Whitlock et al. 2003). These variations have often been shown to be associated with variations in climate. Widespread fires are generally associated with warm, dry years that are produced by phasing patterns of global and regional scale climate-forcing mechanisms (e.g., El Niño/Southern Oscillation and the Pacific Decadal Oscillation) (Swetnam and Betancourt 1998, Kitzberger et al. 2001, Heyerdahl et al. 2003). Developing a better understanding of the temporal and spatial connections between fire and various climate-forcing mechanisms at annual to decadal scales, especially during this period of rapidly changing climate, would allow managers to better plan fire management activities and use of associated resources.

Intensive fire management (especially fire suppression) in the western US has generally helped cause widespread alteration of fire regimes. In contrast, the conifer forests of the Sierra San Pedro Martir (SSPM) of Baja California, Mexico have not experienced intensive fire management (suppression) (Minnich et al. 2000, Stephens et al. 2003). Thus, the fire-scar record of the SSPM extends to the present (Stephens et al. 2003), and may provide important information unavailable in most of the western US concerning responses of fire regimes to the current, rapidly changing climates.

OBJECTIVE

1. To describe spatial and temporal fire regime variation across the conifer zone of the Sierra San Pedro Martir.
2. To assess the influence of climatic factors on fire occurrence patterns and synchrony of widespread fires.

METHODS

We combined data from 257 crossdated, fire-scarred, conifer specimens from 12 sites spatially dispersed across the Sierra San Pedro Martir (SSPM). Ten sites were collected by Burk (1991) and two sites by Stephens et al. (2003). The two Stephens collection areas were approximately 100 ha each and the 10 Burk sites varied from ~4 to ~20 ha in size. The sites ranged from approximately 2000 - 2600 m in elevation (Figure 1). While *Pinus jeffreyi* dominates on all sites, *Abies concolor, P. lambertiana, Calocedrus decurrens,* and *P. contorta* var. *marryana* may be associates.

Sampling on each site was designed to maximize completeness of fire occurrence dates over as long a time-period as possible (Swetnam and Baisan 2003). Each of the 257 specimens used to determine fire history was crossdated with a local tree-ring chronology obtained from the ITRDB using standard dendrochronological techniques (Stokes and Smiley 1977, Swetnam et al. 1985).

FHX2 software was used to store and analyze fire-scar data (Grissino-Mayer 2001). Since the sites differed in size and number of samples collected, we used the software program SSIZ (Holmes 1995, Swetnam and Baisan 2003) to compare the fire occurrence record between sites to determine if they were from similar fire regimes. Output from SSIZ is similar in concept to the use of a species-area curve by botanists to determine adequacy of sample intensity. SSIZ computes an estimated mean number of fires and confidence intervals for different sized, randomly selected sub-sets of sampled trees using a Monte Carlo approach (Swetnam and Baisan 2003). The curve flattens when increasing the number of samples in the randomly selected sub-sets no longer increases the number of fire dates discovered. We expected the mean fire intervals for the 10 Burk (1991) sites to plot within the 99.9% confidence interval of the curves from Stephens et al. (2003) if they were from a similar fire regime.

Superposed epoch analysis (SEA) was used to examine the interannual relationship between fire occurrence and proxy climate indices (Baisan and Swetnam 1995; Grissino-Mayer and Swetnam 2000) – Palmer Drought Severity Index grid point 43 (Cook 2000), Southwestern Drought Index (Cook 2000), El Niño/Southern Oscillation (NINO3) (Cook 2000), and the Pacific Decadal Oscillation (Biondi et al. 2001).

Decadal fire/climate associations were investigated graphically by calculating moving 10-year sums of each index and then standardizing the results for each index so they could be plotted on a common scale. For fire occurrence, we summed the number of sites in which $\geq$ 2 trees were scarred in a year over a moving 10-year period. A site was counted as many times as it met this criterion.

To examine spatial pattern, we used hierarchical cluster analysis (Euclidian distance, Ward's method) to group sites that had similar fire occurrence histories based on fire dates in common (Taylor and Skinner 2003).

RESULTS

Fire Record. 257 specimens with 1,816 fire scars were crossdated from the 12 sites (Table 1).

Table 1. Summary of data for the 12 sample sites.

Site	Samples	Fire Scars	Scars/ Sample	Earliest Ring	Earliest Scar	Last Scar	Median FRI	Yrs of Record
Azul	18	73	4.1	1548	1587	1956	13.5	369
Blan	6	38	6.3	1571	1626	1938	6	312
Coro	14	85	6.1	1477	1601	1963	7	362
Grul	15	82	5.5	1650	1669	1966	6	297
Puer	14	70	5.0	1676	1740	1946	8.5	206
Pyra	15	62	4.1	1693	1752	1956	7.5	204
Pino	16	93	5.8	1487	1722	1959	7	237
Tasa	12	39	3.3	1569	1654	1965	16	311
Vall	19	79	4.2	1553	1688	1973	9	285
West	23	161	7.0	1558	1600	1981	6	381
S1	53	523	9.9	1473	1527	1980	5	453
S2	52	511	9.8	1464	1521	1962	4	441

When mean fire intervals from each of the 10 Burk (1991) sites were plotted on the SSIZ output from S1 and S2, only one site (Pino) plotted within the original confidence intervals (Figure 2). We then subsampled the original Stephens et al. (2003) data to generate new curves for sites with area and numbers of samples similar to those from the Burk (1991) sites since fire-regime descriptors have been shown to be sensitive to sampling area (Arno and Peterson 1983, Falk and Swetnam 2003). Eight of the remaining nine sites now plotted within the confidence intervals (Figure 3). The single site (Azul) that did not plot within the confidence intervals is the highest in elevation and the only site to have *Populus tremuloides* present. Thus, Azul may be generally more mesic and likely is from a different fire regime than the other sites.

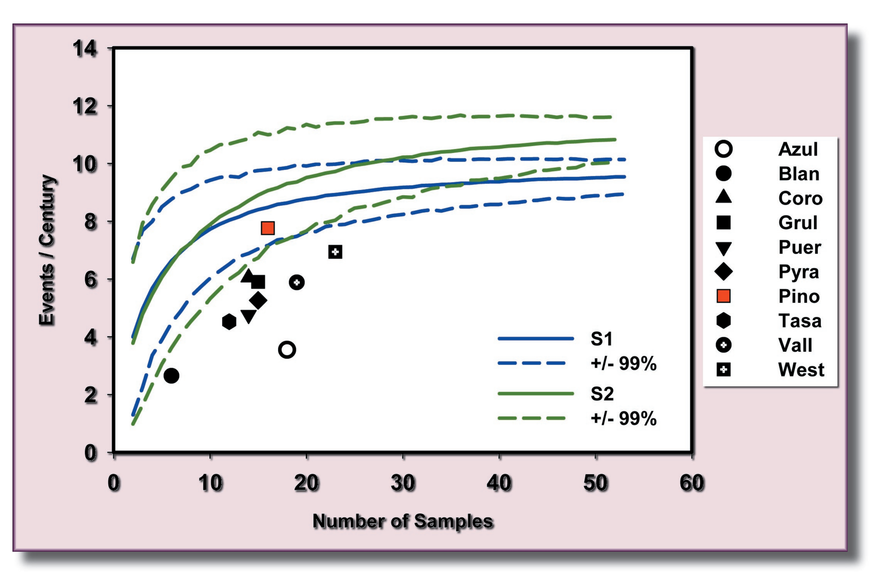


Figure 2.
Plot of mean FRIs for the Burk (1991) sites over the Stephens et al. (2003) results of SSIZ.

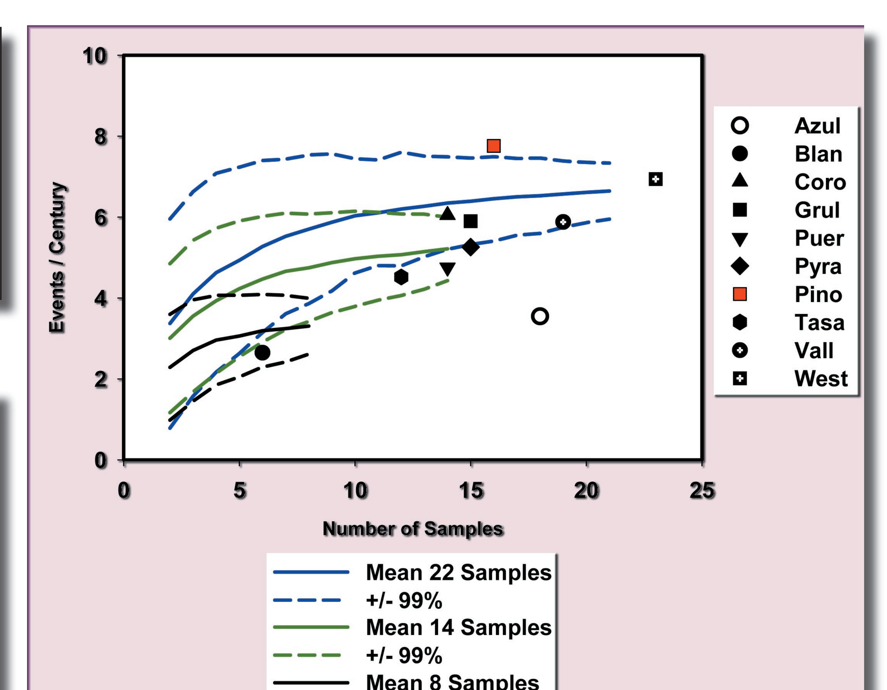


Figure 3.
Plot of mean FRIs for the Burk (1991) sites over the Stephens et al. (2003) SSIZ runs adjusted for area and number of samples.

Fire Record (cont). We used the period of AD 1700-1990 for our analyses since there is rapid decline of sample depth before 1700. In no year was at least one tree scarred on all sites. The most sites scarred in a single year was 8 in 1767. Years in which at least 6 (50%) sites had at least one tree scarred were 1703, 1722, 1751, 1752, 1767, 1777, 1789, 1832, 1851, 1860, 1877, 1899, 1902, 1921, 1928, and 1946. Years in which $\geq$ 10% of trees were scarred on each of $\geq$ 50% of sites were 1777, 1832, 1851, 1860, and 1921. Years in which each site had at least two trees scarred are shown in Figure 4.

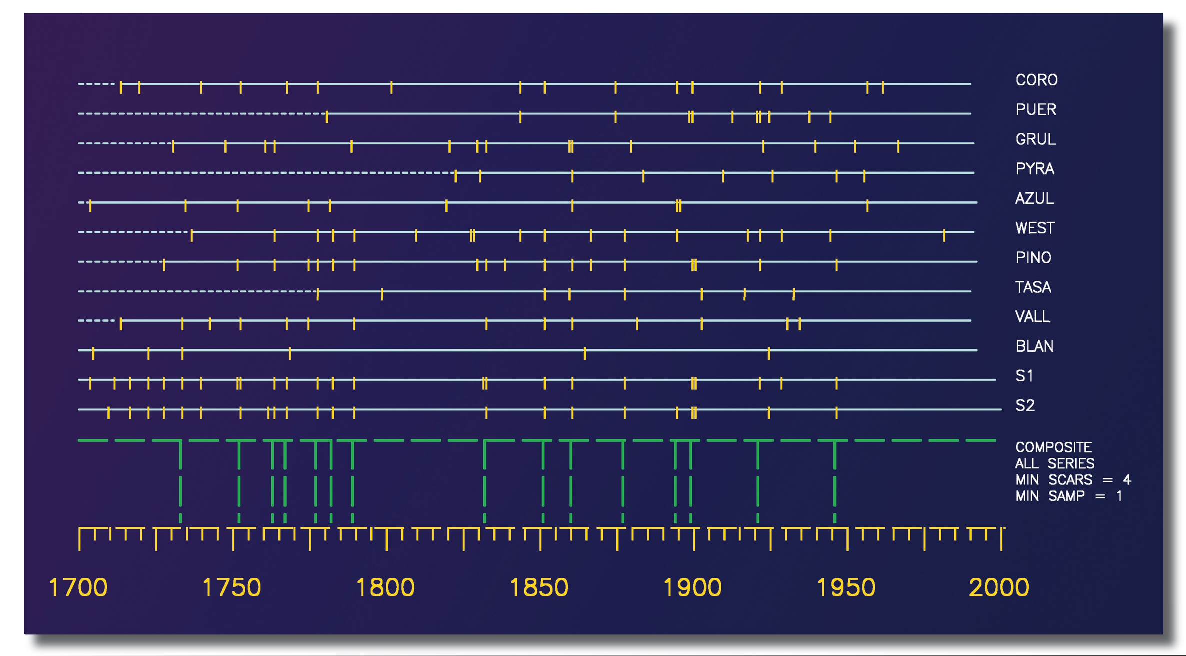
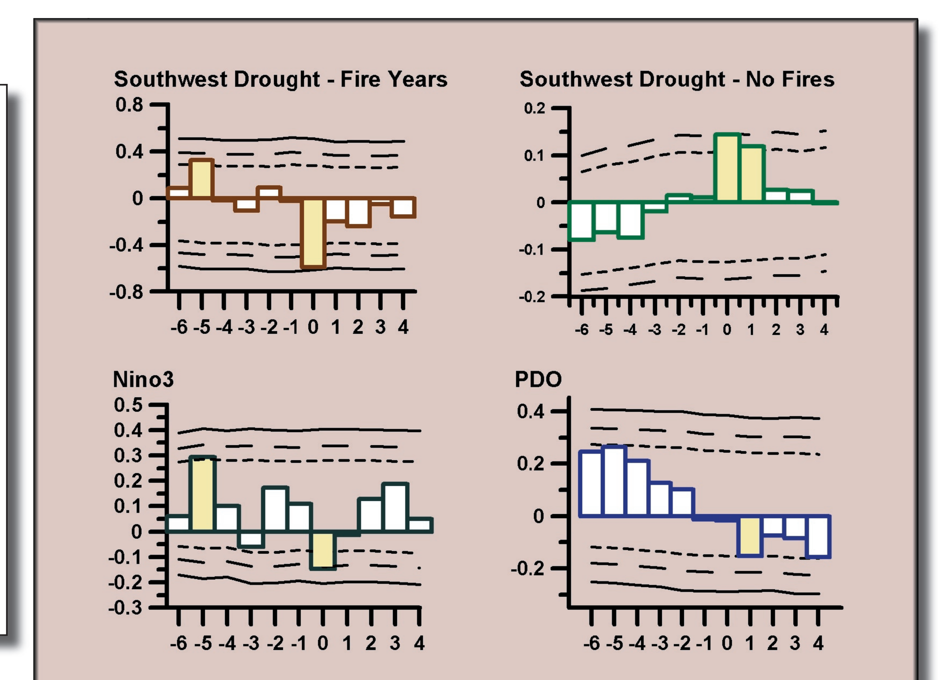


Figure 4.
Plot of composite fire events for each sample site. Each horizontal line represents a site. Each vertical tick represents a fire that scarred at least two trees on the site.

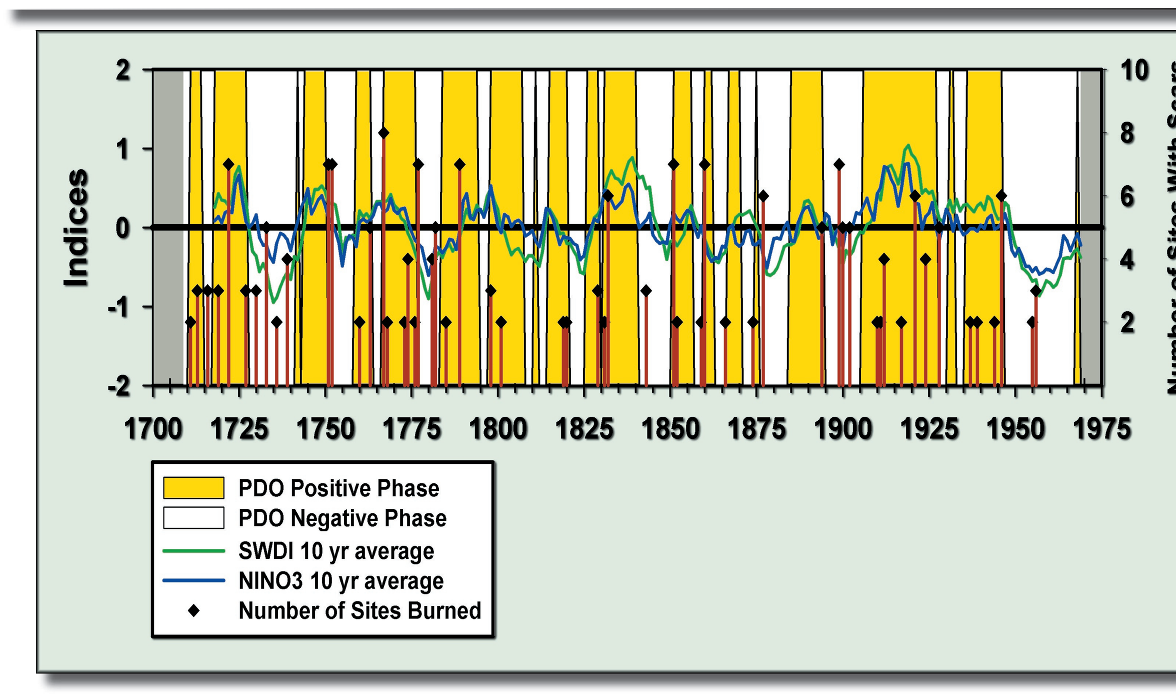
Superposed Epoch Analyses. For the SEA, we used the 32 years in which at least two sites had at least two trees scarred. These events were associated with dry years (SWDI) and ENSO (NINO3). Events appear to be during years when the PDO is changing from a warm to a cool phase. Non-fire years were associated with wetter than average years (Figure 5).

Figure 5.
Results of SEA comparing years of fire events to SWDI, NINO3, and PDO. 0 is the year of the fire. Other years are those preceeding and following the event year. Also shown are the 95, 99, and 99.9% confindence intervals.



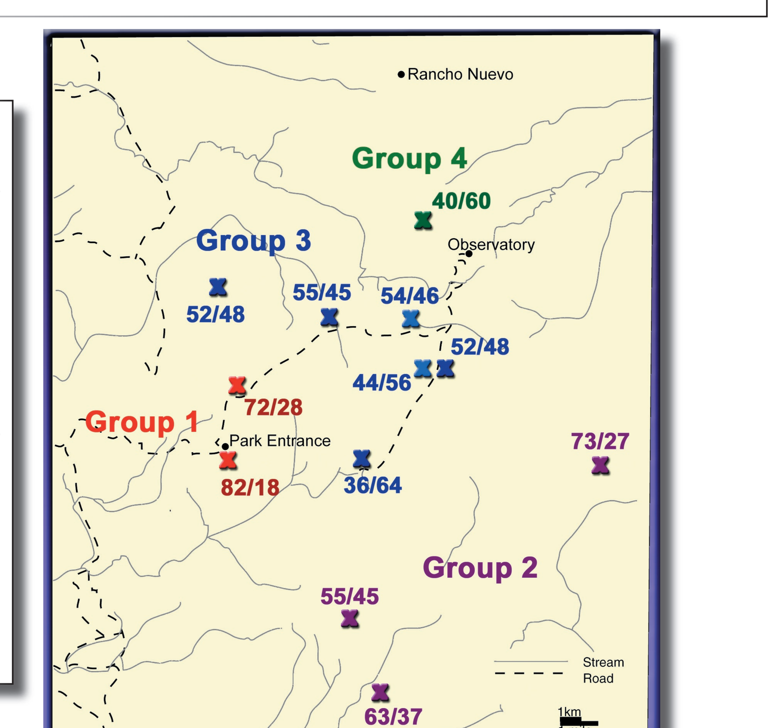
Interdecadal Relationtionships. Figure 6. presents the smoothed time series of NINO3 and SWDI and years with $\geq$ 2 sites each with $\geq$ 2 trees scarred are shown charted over a background of PDO +/- phases. The chart demostrates the association suggested by the SEA of fires tending to occur during transitions of PDO phases. It also appears that more extensive fires are more likely to occur during phase changes. We intend to explore this further.

Figure 6.
Time series plots of smoothed NINO3 and SWDI with fire events plotted over a background of PDO phases.



Spatial Patterns. Clustering of sites using years of fire occurrence resulted in four groups that were spatially coherent and separated from each other by topographic factors (Figure 7). Thus, patterns of fire occurrence tended to be influenced by topographic characteristics, with the timing of fires varying among groups of sites. Patterns of fire season, as indicated by intra-ring position of fire scars, also varied with topography and may be a factor in setting up the differences in timing of fires among sites (Figure 7). These differences in season of burn may be an important component of how topographic influences are expressed, ultimately helping to generate the spatial patterns detected. Generally, lower elevation and exposed sites tended to have scars in the initial part of the earlywood. Whereas, higher sites or those where cold air would pond, generally have scars in latewood or late portions of the earlywood.

Figure 7.
Colors show the four groups of sites resulting from clustering sites with fire years in common. Numbers near each site location indicate percent of fires in the (early-early)/(mid-early to latewood) ring positions. Thus depicting variation in fire season.



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